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Fretting friction and wear characteristics of magnetorheological fluid under different magnetic field strengths

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A B S T R A C T

A magnetorheological fluid (MRF) performs differently under different magnetic field strength. This study examined the fretting friction and wear characteristics of MRFs under a range of magnetic field strengths and oscillation frequencies. The fretting friction and wear behaviors of MRF are investigated using a fretting friction and wear tester. The surfaces of specimen are examined by optical microscopy and 3D surface profilometer before and after the tests and wear surface profiles, the wear volume loss and wear coefficient for each magnetic field strength are evaluated. The results show that the friction and wear properties of MRF change according to the magnetic field strength and oscillation frequency.

1. Introduction

Fretting wear occurs when two contacting bodies are subject to small amplitude oscillatory relative motion [1]. Depending on the conditions, fretting wear can be reduced by either increasing friction or decreasing the amount relative motion between the surfaces or lubricating the contact to decrease friction while allowing relative motion [2]. Fretting in mangy machine elements occurs due to vibrations of the total machinery or system, which cannot be excluded during operation. Many common machine components, such as bearings, leaf springs, hub and shaft, gears, couplings, pin joints, flanges, turbine blade, etc., are subject to the fretting phenomena. Considerable research has been carried out to evaluate the fretting wear characteristics of different materials under a various range of test conditions. The slip amplitude, normal force, fretting cycle duration, environment, and lubrication are a few of the important parameters that affect the fretting wear behavior [3,4]. Such as the material performance of a friction pair, the normal force and frequency of fretting, lubrication condition, magnetic field, and surface treatment [5–9]. Failure of the bearing in machinery due to severe wear has led to total shutdown of the machinery itself, which results in significant replacement time. Fretting wear failure is one of the failure modes frequently observed in many applications. A few studies have been reported the fretting wear behavior of bearing steels [10–12].

Magnetorheological fluid (MRF) is a suspension fluid that is prepared by small magnetic particles (micro-level) dispersed in an insulating carrier fluid, and shows specific non-colloidal MR characteristics according to the external magnetic field. With such unique mechanical properties, the MRF can be used widely in various applications, such as dampers, clutch systems, and sealing systems [13,14]. The rheological properties of MRF are directly related to friction, which means that MRF shows different friction performance under different magnetic fields. Therefore, the effects of the magnetic field on the frictional movement have been studied, experimentally and theoretically. Sato et al. reported the effects of a magnetic field on fretting wear. They found that the fretting wear in dry contact conditions is increased under the influence of magnetic field [8]. Ultrasonic velocity and amplitude characterization of magnetorheological fluids under magnetic fields has been studied by Rodríguez-López et al. [15]. Moreover, Shahrivar et al. reported the tribological performance of ferrofluids and magnetorheological fluids within steel–steel point contacts [16]. The reciprocating sliding friction behavior of MRF with different material types and magnetic field strengths has been studied [17]. However, the influence of fretting wear under magnetic field with magnetorheological fluid lubrication conditions has not been studied. Therefore, this study examined the fretting friction and wear characteristics of MRF under different magnetic field strengths and oscillation frequency conditions.

The friction and wear tester for MRF under fretting conditions is configured. The strength of a magnetic field is controlled by an electromagnet implemented below the specimen. The friction

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coefficients were measured and compared according to the strength of a magnetic field applied to the MRF and different oscillation frequency conditions. The surfaces are analyzed before and after the tests to determine how the MRF affects the surface under fretting conditions. In addition, the wear properties were examined.

2. Experimental specimens

A fretting friction and wear tester is designed with a displacement sensor, load cell, temperature sensor, and speed-controllable AC motor (SPG®/9I180DB-V12). Fig. 1 presents a schematic diagram and photograph of the fretting friction and wear tester. The loading devices are installed on the tester: an S beam load cell (BONGSHIN®/DBCM-100 kN) is used to measure the friction force (*F*) in the horizontal direction, and the compression load cell (BONGSHIN®/CDFSB-200 kN) is used to measure the applied load (*N*) in the vertical direction. The measured values are collected by indicators and transferred to a personal computer by Labview to calculate the coefficient of friction. The coefficient of friction was calculated using the measured force as follows:

$$\mu = \frac{F}{N + N_0} \tag{1}$$

Where μ is the coefficient of friction, *F* is friction force, *N* is the applied load and N_0 is dead load which has been measured with120 N.

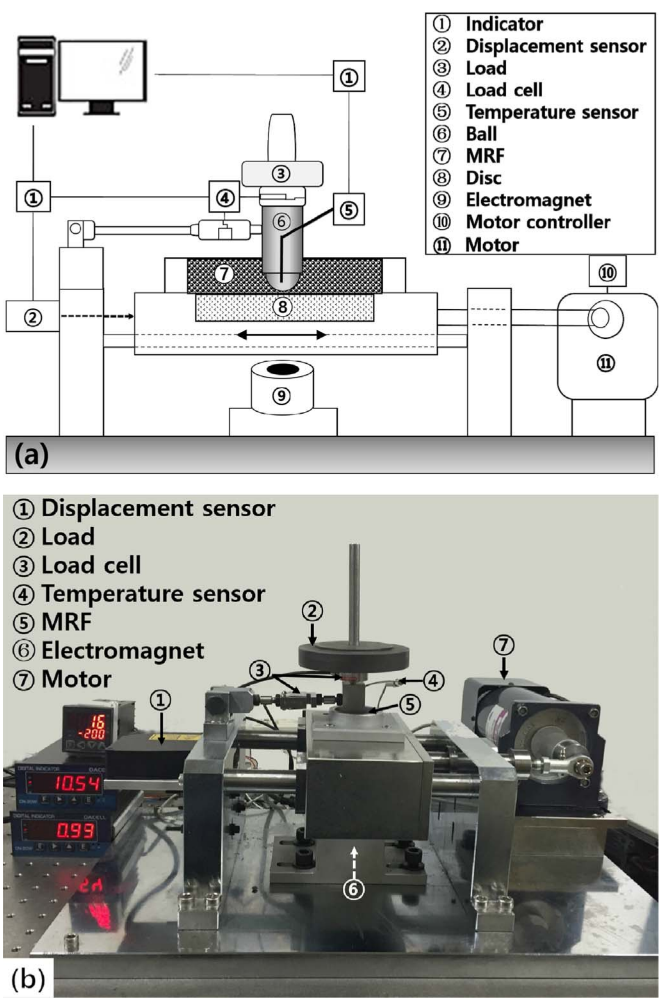

Fig. 1. Fretting friction and wear tester: (a) schematic diagram of the tester (b) photograph of the tester.

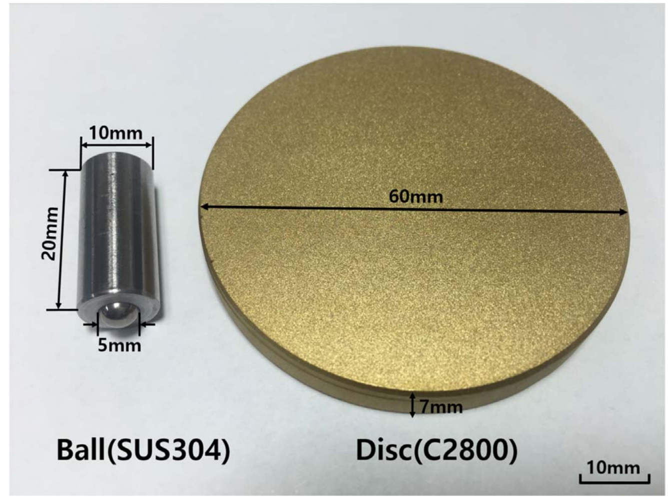

Fig. 2. Specimen of the ball and disc.

The sensors can measure a load of up to 1000 N. Oscillatory motion is applied using a motor with a crankshaft. The disc holder is made of SUS304 to prevent magnetization. The magnetic field strength of the electromagnet could be altered by the electric current applied during the tests. A magnetic field strength of up to 25 mT could be applied. The stroke has been set to 200 μm, and it could be adjusted by the various crank offsets of the crankshaft. The oscillation frequency could be adjusted by the rotating speed of the AC motor, and the maximum oscillation frequency could be set to 30 Hz. The stroke distance could be confirmed by the laser displacement sensor (SICK®/OD Precision) in the experimental process. The location measurement is accurate to the micron level. In order to avoid the influence of magnetic field for test, the ball is made from the stainless steel (SUS 304) and had a diameter of 5 mm, which is fixed tightly inside the ball holder. The disc is made of brass (C2800) with a diameter and thickness of 60 mm and 6 mm, respectively. Fig. 2 presents a specimen of the ball and disc.

In this study, the tests are carried out under different magnetic field strengths and oscillation frequencies, and both the ball and the disc are cleaned thoroughly by an ultrasonic cleaner with acetone prior to each test. Every test is started with a new contact between the ball and the disc. The obtained data are sorted to analyze the relationship between the travel cycle (one period of oscillation) and friction coefficient on the surface with the lubrication of MRF-132DG. Table 1 lists the properties of MRF-132DG from Lord Corp. MRF-132DG is dark gray liquid with a density of 2.95–3.15 g/cm^3 and a viscosity at 40 °C of 0.112 ± 0.020 Pa s. Table 2 provides details of the conditions for the reciprocating test. The oscillation frequency is adjusted by the rotating speed of the AC motor. An additional experiment is carried out for the MRF under the test conditions with a magnetic field strength of 0, 5, or 10 Mt. Since the magnetic field strength of up to 25 mT can be

Table 1
Properties of MRF-132DG (Lord® Co.).

Property	Values
Density (g/cm^3)	2.95–3.15
Phase change time (ms)	1–2
Operating temperature(�)	−40 to +150
Viscosity at 40 °C (Pa s)	0.112 ± 0.020
Particle size(μm)	1–4
Appearance	Dark Gray Liquid